Flood Warning and Response System for the Susquehanna River

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Abstract

The U.S. Army Corps of Engineers, Philadelphia District has developed a Flood Warning and Response System (FWRS) for 110 miles of the main stem of the Susquehanna River in northeast Pennsylvania. The objective is to provide accurate and timely warnings in order to maximize response time for floodplain residents and emergency managers while also creating a floodplain management and planning tool for the region. The project incorporates aerial photography, terrain elevation data, channel geometry, demographic and structural data, and transportation systems with a hydraulic model to create an automated and interactive flood inundation mapping application using Geographic Information Systems technology.

The Corps' Hydrologic Engineering Center (HEC) developed a hydraulic model for the complete project area. Multiple discharge profiles for flooding events were established and mapped on the elevation model. The functionality of the FWRS is based on river stages at four stream gages located within the project area. A known or predicted stage at one or more of the gage locations produces the appropriate flood inundation layer as a depth grid. Using the depth grid and underlying base data, determination of extent and depth of flooding as it impacts buildings and transportation systems and expected damages to structures and contents are readily available through the user interface.

Timely estimates of the severity of flooding will better equip emergency management officials to identify those at risk and plan for evacuations accordingly. It will also allow affected property owners the opportunity to minimize potential damages. In addition, preliminary damage estimates may be furnished to FEMA in advance or during a high water event so that disaster relief may be expedited.

Purpose

This paper describes the development of a Flood Warning and Response System (FWRS) that will provide local communities along the Susquehanna River, PA with accurate and timely warnings to maximize response time for emergency management officials and floodplain residents. The Geographic Information System (GIS) based FWRS application allows users to visualize floodplain inundation extent and depth based on a forecasted river stage at one or more of the four river gage locations along the Susquehanna River. The flood inundation mapping, in conjunction with the variety of base data that can be displayed concurrently, allows managers to identify potentially hazardous areas and prepare and execute flood response measures to alleviate the loss of life and mitigate structural damages.

Study Scope

The project area for the Susquehanna River FWRS is a portion of the area generally referred to as the Wyoming Valley. The Wyoming Valley is in the northeast to north-central portion of Pennsylvania, about 90 miles northeast of Harrisburg. As shown in Figure 1, the FWRS covers approximately 110 miles of the main stem Susquehanna, specifically the flood prone areas of Columbia, Luzerne, Montour, Northumberland, and Snyder counties. The major cities in the project area are Bloomsburg, Danville, Selinsgrove, Sunbury, and Wilkes-Barre.

History

The Wyoming Valley area has experienced several damaging flood events over the years, including the flood of 1936, which prompted the authorization of the original levee system in the project area (USACE, 1995). The worst flooding experienced occurred in June 1972 and was brought about by the heavy rainfall associated with Tropical Storm Agnes. The high flows caused by Agnes overtopped the levees that were in place and caused estimated damages of $1 billion (Times Leader, 1998). Since 1972, several high water events have reached peak stages close to the levee crests, most recently in January of 1996. In the Spring of 1997, the Baltimore District of the U.S. Army Corps of Engineers, through the Wyoming Valley Levee Raising Project, began work to complete raising and improvements to the levee systems in the area (USACE, 1995). The $175 million project includes structural and nonstructural measures and is intended to provide protection against an Agnes level event. The mitigation plan includes $23 million for property acquisitions, structure raisings, structure flood-proofing and small-scale public works projects. The Philadelphia District is developing the FWRS to be part of the non-structural improvements to the overall flood control system for the area at a cost of approximately $2 million. The applicability of the results to all Federal, State and Local agencies, special interests, private entities, and the general public have been considered in the implementation and design of the system.

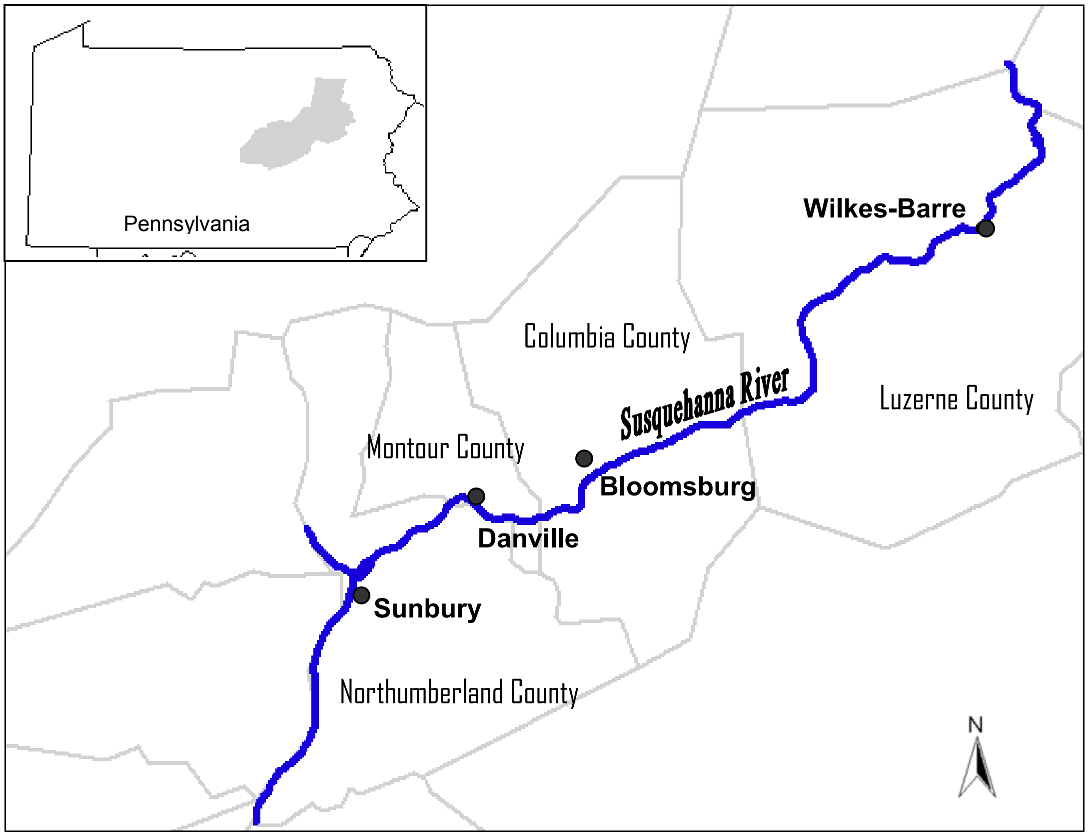

Figure 1. Susquehanna River, Pennsylvania study area location.

Data Collection

Detailed mapping data were collected within the estimated 500-yr floodplain area, approximately 115 square miles of data coverage. These data include building footprints for all structures, spot elevations for all corners of structures, the transportation networks, river depth surveys, digital ortho-photographs, and a digital elevation model capable of producing a 2 ft contour interval. Detailed demographic data for structures within the approximate 100-year floodplain were collected and include, where available, the property owner's name, address, phone number, digital photos, first floor elevation, a notation as to the existence of a basement, the total number of stories, assessed value, and a description of the building's use or the type of business.

The detailed mapping data were used to develop a hydraulic model and to create a basis for the flood inundation mapping. The demographic data were used to provide a basis for damage estimates for a range of flood depths.

Hydraulic Analysis

The Susquehanna River hydraulic analysis was performed using the River Analysis System (HEC-RAS) (HEC, 2003a). Approximately 110 river miles were modeled using geometric data derived from the digital data collected for this study. HEC-

GeoRAS (HEC, 2003b) was used to extract geometric data including cross-sectional elevations, Manning's *n* value, levee, and ineffective flow data.

Flow Data

The hydrology data for the HEC-RAS river hydraulics models were developed in two data sets: a calibration data set and an inundation mapping data set. The calibration data set was developed based on flow frequency data at USGS gaged locations, while the inundation mapping data set was developed to cover a range of flow events.

Calibration data were developed from USGS gaged data at Wilkes-Barre, Bloomsburg, Danville and Sunbury on the Susquehanna River and at Lewisburg on the West Branch. Between gage locations, flow was distributed based on drainage area. The calibration data were used to adjust model parameters to best represent the river geometry.

The inundation mapping data are comprised of flow events ranging from a low-flow event of 80% of the 0.5% chance exceedence to a high-flow event of 120% of the 0.002% chance exceedence event. The inundation mapping data were used to create a series of water surface profiles that bound the expected range of river stages along the Susquehanna River. The final inundation map set includes 35 water surface profiles having an elevation difference between profiles of approximately 1 ft at each cross section.

Geometric Data

Geometric data were derived at each cross section using the HEC-GeoRAS software in ArcView GIS. Parameters extracted using GeoRAS included elevation data; Manning's *n* values; levee positions and elevation; and ineffective flow data. Thirty-one bridges were entered into the hydraulics model. Calibration of flow data to observed data required an iterative process of extracting geometric data from GIS data, modifying geometry and parameters, and hydraulic model simulation. Initial calibrations to low flow data indicated problems with channel geometry.

Cross-sectional data was extracted from a ground surface TIN created by the Philadelphia District and later modified by HEC to add levee features. The terrain model was developed from two data sources: an aerial survey that coveres the overbank areas and a hydrographic survey of the submerged channel. The hydrographic survey data consists of cross sections surveyed at approximately 1 mile intervals. The channel between the surveyed cross-sections was interpolated using the "Channel" program, which was developed by the Philadelphia District's GIS section. The interpolated data were then merged with the overbank data to create the complete terrain model. Problems were encountered with the resulting channel in the transitions around numerous islands in the Susquehanna River.

To address the channel interpolation problems, aerial photos, the flow corresponding to the aerial event, and surveyed cross sections were used to modify cross sections within HEC-RAS to properly reflect channel conveyance. A GIS polygon data set was created at the extent of the flow event observed in the aerial photos. Working within the framework of GeoRAS, the polygon data set was used as an ineffective flow area theme to find the intersection with the cross section cut line theme. The intersection of the ineffective areas with the cross sections bounded the inundated portion of the channel as portrayed in the aerial photos. Further, these lines represented the bounds of the two data sources: data from the aerial survey were outside of the "ineffective lines" and data from the "Channel" program were inside the lines .

Many cross sections did not have a well-defined low flow channel, indicating the interpolation of the cross-sectional data at these sections was deficient. An example of a cross section with poor channel data is shown in Figure 2.

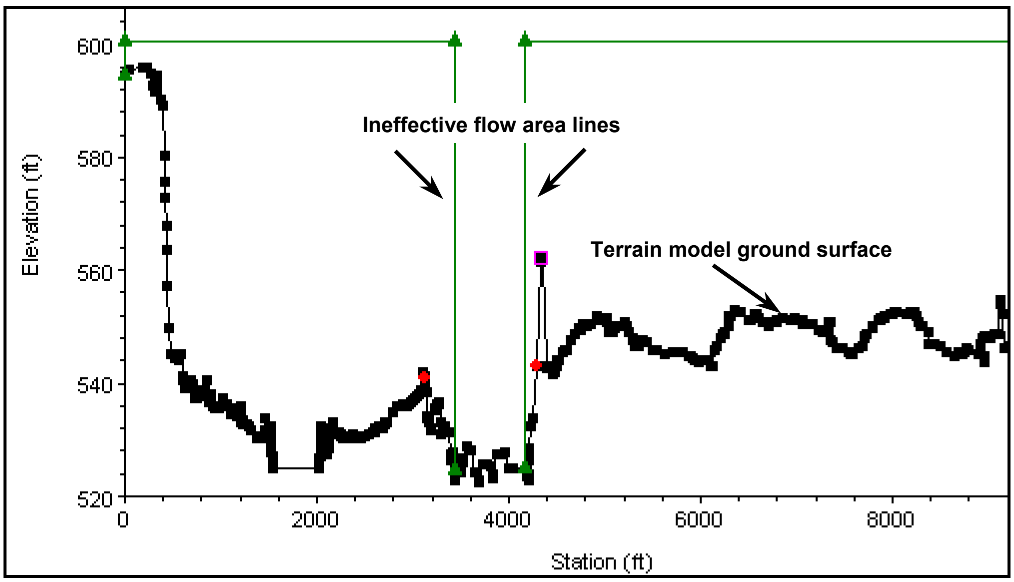

Figure 2. Cross section with ineffective flow area lines indicating low flow channel.

This problem was generally evident at sections that transitioned to or from sections with islands in the main channel. However, poor interpolation also occurred through meandering sections of river where the thalweg moved from one side of the channel to the other. Cross sections were graphically edited to have an appropriate invert elevation and adequate conveyance area. The water surface profile was then simulated for the recorded flow at the time of the aerial survey. This process was repeated until an acceptable geometry was developed. This process required an understanding of river morphology and engineering judgment. An example of the modified cross section to account for a low flow channel is shown in Figure 3.

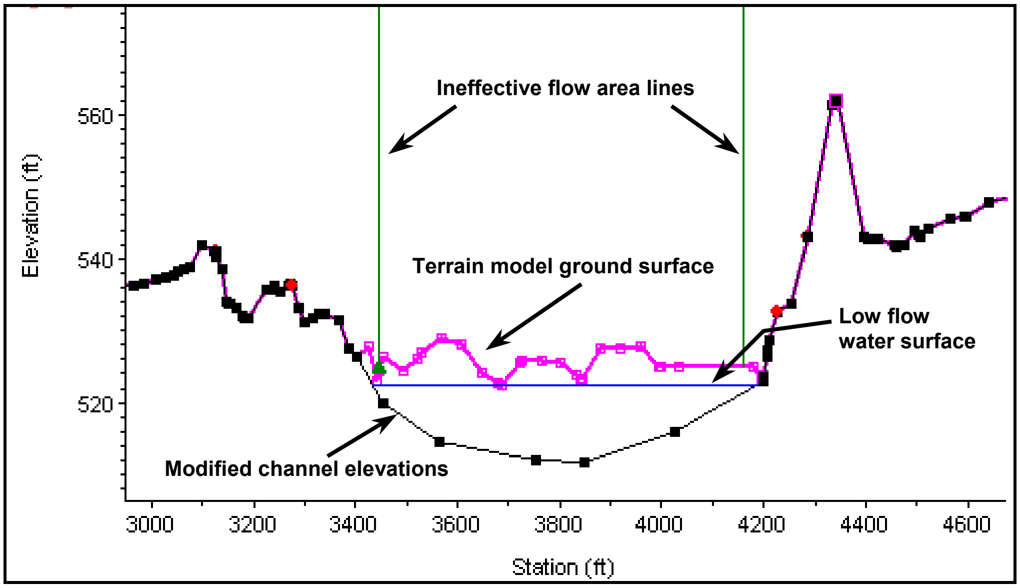

Figure 3. Cross section with modified channel.

<u>Manning's *n* Values</u>

Manning's *n* values were estimated from land use patterns visible in the aerial photos. A polygon data set was created by delineating a polygon for each land use type and a lookup table was generated for the corresponding *n* value. The *n* values were extracted using GeoRAS. The initial estimated Manning's *n* values are shown in Table 1.

Table 1. Initial Manning's n Values

Land Use	Manning's *n* Value
River Channel	0.030
City Area	0.120
Open and Farmed Fields	0.050
Forests	0.065
Ponds	0.030

Manning's *n* values were adjusted in the calibration process to match water surface profiles with observed stages at gages and high water marks. This initial calibration focused on the 1% change exceedence event. Further calibration to the range of flow events required the use of a flow roughness change with flow. In general, flow roughness was increased for larger flows and decreased for smaller flows.

<u>Ineffective Flow Areas</u>

The ineffective flow areas are used to identify regions that do not actively convey water downstream. Typical locations for ineffective areas are at the contraction and expansion of flow through a bridge. Because of the numerous bridges along the river, development of these areas in plan view using the GIS was very beneficial. Ineffective locations along each cross section were extracted using GeoRAS. Trigger elevations were adjusted within HEC-RAS based on bridge and channel geometry.

Levee Positions

Levees were incorporated into the terrain TIN from CAD drawings. Using the aerial photos and terrain information, levee positions and elevations were located and extracted using GeoRAS.

Inundation Mapping

HEC-RAS results were imported into HEC-GeoRAS and processed to create flood inundation maps.   Thirty-five water surface profiles were processed to generate an atlas of floodplain boundary maps and depth grids.

Exported HEC-RAS results were imported to the GIS using GeoRAS. Initial floodplain boundary maps were developed and compared with floodplain geometry. Obvious errors in floodplain delineation due to incorrectly modeled geometry were corrected in HEC-RAS. Profiles were then recalculated, exported, and processed by GeoRAS. After exhausting the geometric modifications in HEC-RAS to produce appropriate delineations (such as adjusting levees to overtop together or changing the cross-sectional layout), the final water surface profile results were exported. An example flood inundation map is shown in Figure 4.

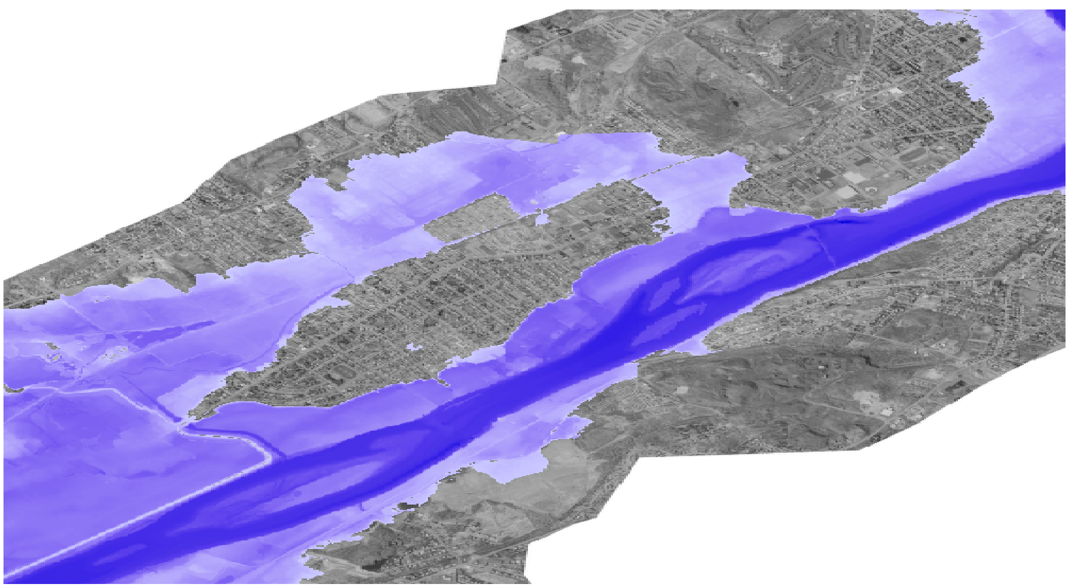

Figure 4. Aerial photograph overlaid with a flood depth grid.

When the final HEC-RAS results were imported to the GIS and processed using GeoRAS, improper floodplain delineations were still apparent. Final inundation results were developed by modifying the bounding polygon to properly account for inundation. The greatest uncertainty in floodplain delineation lies with the extreme flood events that overtop levees where small channels, ridges, culverts, curbs, and gutters control flows. Therefore, isolated pockets of floodplain inundation were not removed from the final inundation results. Further, this inundation will give forecast personnel a conservative estimate of low-lying floodprone areas where local floodplain knowledge may be applied in real time.

Flood Damage Analysis

An urban flood damage calculation system, accessible through the flood warning software, was developed to assist in the flood response decision-making process, allow for early estimate of flood damage, and expedite disaster relief preparations. The flood damage calculation system computes damages to single structure or groups of structures and predefined impact areas or counties for a given event.

To develop the Susquehanna River data for the damage calculation system, two programs were populated and run. Using individual structure data and water surface profiles for eight events ranging from the 0.999 to the 0.002 exceedence probability, the HEC Flood Damage Analysis program (HEC-FDA) was run to develop stage vs. damage functions for impact areas along the river (HEC, 1998). A total of 56 impact areas were identified in the study area. The impact area delineations were based on boundaries for local municipalities in the area.

HEC-FDA computes stage vs. damage functions for an impact area by stepping through each structure and computing the damage to that structure for each frequency event. The damage over the range of frequency events is aggregated for all structures in an impact area. Damage to a structure is computed by first finding the water elevation from the nearest cross-section for an event, then comparing that elevation to the first floor elevation of the structure to compute depth of flooding at the structure. Next, the percent damage to the structure and contents is calculated from the depth vs. percent damage function for the structure type. The percent damage to structure and contents is then multiplied by the structure value and content value to give the total damage to that structure for that event.

After the stage vs. damage functions were computed by HEC-FDA, the Flood Impact Analysis program (HEC-FIA) was used to compute damage in the impact areas for each of the 35 inundation maps that were created using GeoRAS. HEC-FIA computes event damage based on a hydrograph at a given location (HEC, 2003c). The 35 inundation maps were converted into peak stage hydrographs at points adjacent to each impact area. HEC-FIA compares the peak stages to the impact area stage vs. damage functions to compute the damage in an impact area for the given event.

Flood Warning and Response System

The Flood Warning and Response System (FWRS) software is a tool bar that runs in ArcGIS and is designed to use real-time forecasts to visualize hazardous areas (HEC, 2003d). The FWRS tool bar is shown in Figure 5.

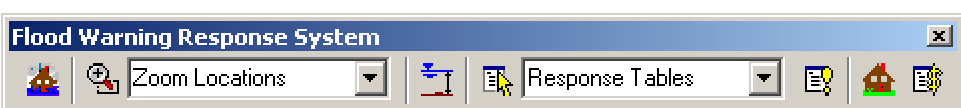

Figure 5. Flood warning and response system tool bar.

From the FWRS tool bar, a dialog is accessed that allows the user to enter an observed or forecasted stage at one or many of the gages along the Susquehanna River: Wilkes-Barre, Bloomsburg, Danville and Sunbury. Upon entering a forecasted river stage in the dialog shown in Figure 6, inundation depth grids are automatically loaded into the GIS. Zooming to predefined locations is readily available to examine floodprone areas. Users can query inundation depths, identify flood response actions, identify impacted structures, and compute structural and content damage from tools and buttons available in the FWRS.

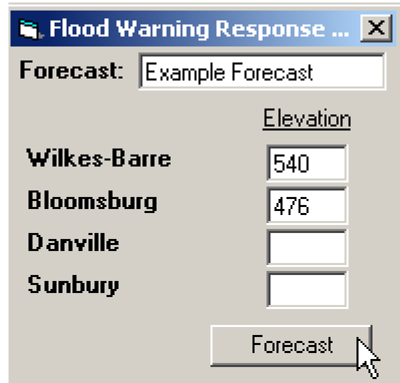

Figure 6. Forecast data entry.

GIS Data Layers

Background GIS data are automatically displayed when a flood forecast is displayed. Default background data includes an aerial photograph of the system and the location of cities, roads, bridges, and counties boundaries. Users may define additional data sets and the symbols for display using ArcMap functionality.

Depth Grids

Depth grids were developed for the entire Susquehanna River study area based on the specific gage areas. This provides flexibility in specifying the forecasted or observed stage at each gage individually and allows the user to view only the depth grid of interest in their community. Therefore, localized events along the river may be considered.

The depth grids are used to query floodplain inundation depths and calculate individual structure damage. Depth results are displayed in the dialog shown in Figure 7. Results show the flood depth, gage used for the depth grid, reference flood elevation calculated by HEC-RAS, and elevation forecasted.

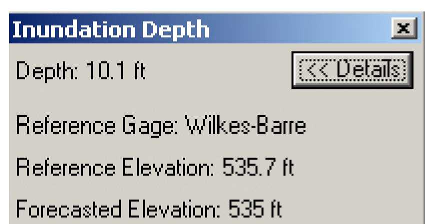

Figure 7. Inundation depth results.

Flood Impact Response Tables

Flood impact response tables are stored in an Excel spreadsheet. Each site-specific response table is entered on one Excel worksheet with the flood impact response table workbook. This allows for customization of impact response tables by each community. During a flood forecast, these tables are accessed through the FWRS interface.

In addition to customizing the impact tables for stage and response, the tables may also be customized for display properties. Therefore, actions may be colored by severity for easy recognition to forecasters. When viewing the response table, the forecasted elevation is highlighted for quick reference. An example flood impact response table is shown in Figure 8.

Flood Impact Response Tables

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	Elevation	Stage	Impact	Response
Exeter Borough	554	32	Main St. Shickshinny Inundated	County Installs Barrier Erie-Lackawanna RR Tracks, Swoyersville
	555	33	Inundation: Mocanaqua	Kingston Installs Stop Logs, Pocono-NE RR Tracks. W-B Installs Barrier at rear of C.H.
	556	34		Kingston Installs Sandbag Closure, RT. 11 Edwardsville. W-B Installs Enclosure at Market St Bridge
	557	35	Inundation: RT.11 Edwardsville, Dundee Area, Hanover Twp.	
	558	36	Inundation: Nescopeck B.	County Installs Sill, Lehigh Valley RR Tracks, Swoyersville.
	559	37	Levee topped - Inundation W-B	County Installs Sandbag Closure, Wilkern St. Exeter.
Wilkes-Barre City	540	31	Duryea & W. Pittston affected	Hanover Twp. Installs Stop Logs Canadian Pacific RR Tracks Hollenback PK. W-B Mark Plaza EDW.
	541	32	Main St. Shickshinny Inundated	County Installs Barrier Erie-Lackawanna RR Tracks, Swoyersville
	542	33	Inundation: Mocanaqua	Kingston Installs Stop Logs, Pocono-NE RR Tracks. W-B Installs Barrier at rear of C.H.
	543	34		Kingston Installs Sandbag Closure, RT. 11 Edwardsville. W-B Installs Enclosure at Market St Bridge
	544	35	Inundation: RT.11 Edwardsville, Dundee Area, Hanover Twp.	
	545	36	Inundation: Nescopeck B.	County Installs Sill, Lehigh Valley RR Tracks, Swoyersville.
Shickshinny Borough	519	28	Inundation: Canal St. W. Nanticoke	Close RT. 11 W. Nanticoke
	520	29	Inundation: PP&L Riverlands, River Rd, Por Balanchard, Ws Pittston	Close RT. 11 Shickshinny
	521	30	Inundation: RT.11 Avondale Flooding C.H. Subbasement, Main St. Shickshinny from sewers.	Activate W-B Brookside Flood Protection System
	522	31	Duryea & W. Pittston affected	Hanover Twp. Installs Stop Logs Canadian Pacific RR Tracks Hollenback PK. W-B Mark Plaza EDW.
	523	32	Main St. Shickshinny Inundated	County Installs Barrier Erie-Lackawanna RR Tracks, Swoyersville
	524	33	Inundation: Mocanaqua	Kingston Installs Stop Logs, Pocono-NE RR Tracks. W-B Installs Barrier at rear of C.H.

Figure 8. Summary flood impact response table.

Flood Damage Tables

Flood damage tables, developed for the range of forecast events summarize dollar-damage on an impact area basis. Users can view these tables or individual structure damage tables for any structure or group of structures they select. As shown in Figure 9, along with dollar damage, the structure damage tables list name, address, and flood depth properties. Each table provides easy access to print or save the summary results of impacted structures.

Flood Damage by Structure

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Name	Address	City	Depth (ft)	Damage ($)
JOHN DOE	123 PIPER PL.	SELINSGROVE	6.1	4757
JANE DOE	56 SPARROW LN.	SELINSGROVE	5.7	18212
SALLY MCDONALD	3 RIVER DR.	SELINSGROVE	5.6	7245
MAX SMITH	1823 TREE ST.	SELINSGROVE	6.5	12097
JOSHUA CARL	22 BROWN ST.	SELINSGROVE	6.2	662
CAMERON BAXTER	3814 TULE CT.	SELINSGROVE	6.4	5811
MARK BRIAN	1989 KAMIA PL.	SELINSGROVE	7.6	10063
J. MILLER	89 GOLF DR.	SELINSGROVE	7.9	5467
CHRIS LEGOOD	324 ABBY RD.	SELINSGROVE	8.6	16991
Total =				81304

Figure 9. Table of flood damage by individual structure.

Conclusions

The Susquehanna River Flood Warning and Response System provides an interface for floodplain managers to estimate flooding given observed or forecasted river stages. The visual display of floodplain delineations will assist local communities to identify hazardous areas and the associated flood impact response tables will allow officials to execute flood response measures to alleviate the loss of life and mitigate flood damage. Successful implementation of the FWRS will rely upon accurate and timely stage forecasts, well-established flood action plans, and successful implementation of response activities.

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